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FY90 End of Fiscal Year Letter
(01 Oct 1989 - 30 Sep 1990)

ONR CONTRACT INFORMATION

Contract Title: GaAs/AlGaAs Electronics and InGaAs(P) Optoelectronics on InP Substrates by Gas Source MBE

Performing Organization: University of Illinois

Principal Investigator: H. Morkoc

Contract Number: N00014-88-K-0724

R & T Project Number: 212G006---04

ONR Scientific Officer: Dr. Yoon Soo Park

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Enclosure (1)

ONR YEAR END ANNUAL LETTER

A. Description of scientific research goals

Our research goals are to design and implement novel schemes in order to utilize the optical and electrical properties of III-V semiconductor devices grown by MBE and to enhance their performance. Intimately tied to this is the characterization of optical devices such as modulators, lasers, and detectors as well as an understanding of the underlying optical processes involved. GaAs based materials as well as InGaAs and InP material systems are investigated for possible optoelectronic integration. Thus the wavelength of operation of the optical devices studied ranges from $\approx 0.8\mu\text{m}$ to $1.55\mu\text{m}$ in the infra-red spectrum.

Specifically, by using Gas Source MBE (GSMBE), we intend to obtain high quality InP based materials as well as GaAs electronic devices grown on InP substrates. The latter being an initial step towards the optoelectronic integration of GaAs with InP. GSMBE provides excellent control over the AS/P ratio which cannot be achieved by conventional solid source MBE. Utilization of this technique will lead to the realization of low threshold, low current density CW laser in InGaAsP material system. It will also facilitate the growth of high quality lattice matched InGaAs on InP in conjunction with InAlAs/InGaAs MQW lasers and photodetectors operating in the $1.3\mu\text{m}$ - $1.55\mu\text{m}$ range.

Secondly, the extension to higher wavelengths of operation of GaAs based optical detectors will be sought. This is achieved by incorporating small band gap materials such as Ge or strained InGaAs/GaAs MQW into GaAs based detectors. Electrical and optical properties of Ge/GaAs devices will be investigated for possible optoelectronic integration of Ge based optical detectors with high gain GaAs/Ge HBTs.

B. Significant results in the past year

- The entire GSMBE construction has been completed. All the gas cabinets have been properly placed in the gas penthouse and proper monitoring of processes and safety measures have been installed. The gas manifold and gas panel have been tested for proper functioning and have been outgassed. All the training and procedural matters regarding the gas handling

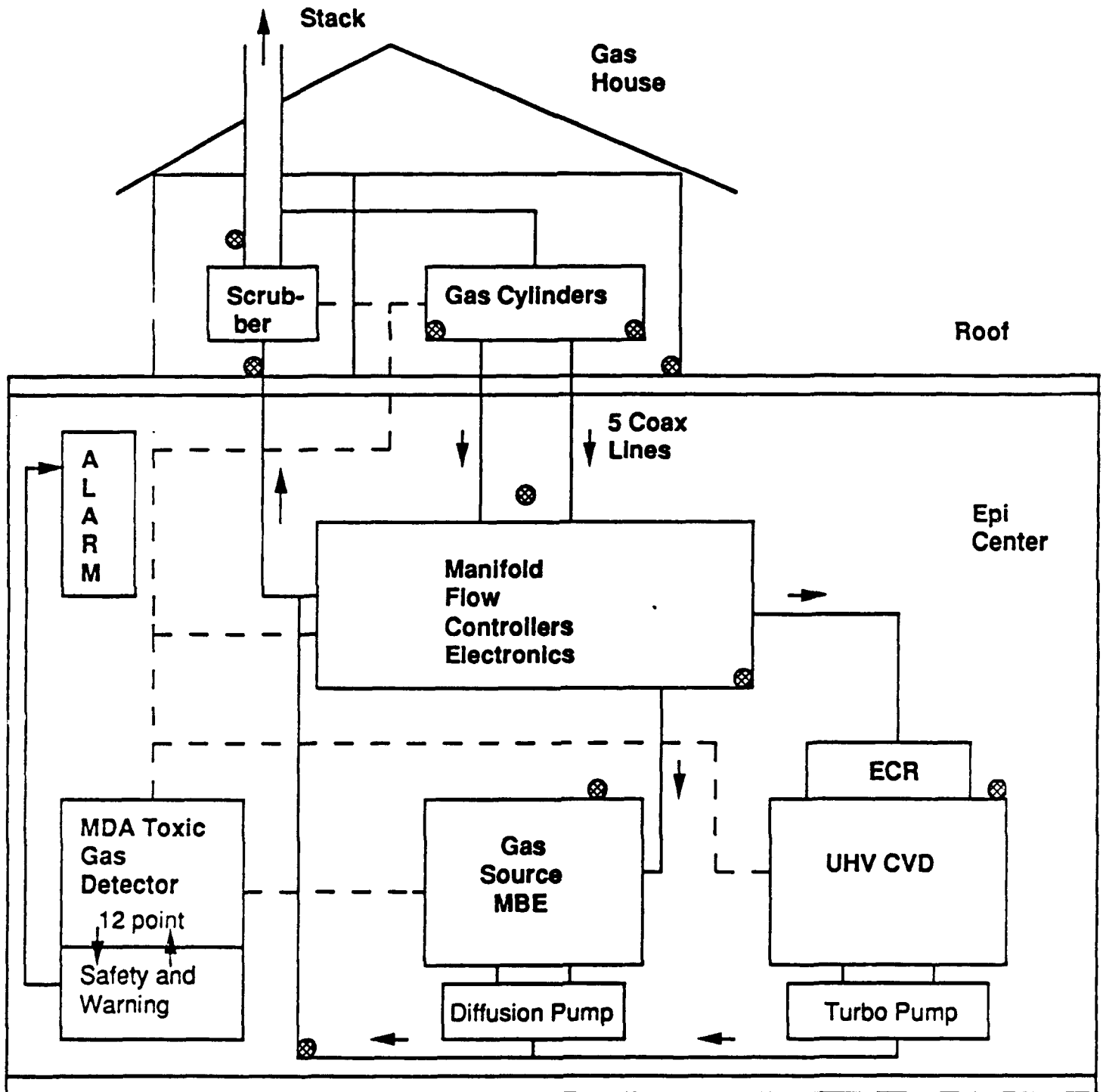
have been completed and the system should be functional by the end of October 1990. A diagram of the GSMBE system has been included with this report.

- Gain and spectral response of Heterojunction Phototransistors having a thin ($0.1\mu\text{m}$) InGaAs strained absorbing layer in the collector have been investigated. Low dark current $\approx 5\text{ pA}$ ($1 \times 10^{-8}\text{A/cm}^2$) and large optical gain, as high as 500, were observed. A resonant cavity composed of an AlAs/GaAs buried mirror structure (Reflectivity, $R=0.9$) and the epilayer surface ($R=0.3$) was used to enhance the otherwise small quantum efficiency η (at InGaAs absorption wavelength). For a 1000 \AA absorbing layer an improvement of η from 6.7% to 43% (6.4 fold) was demonstrated, in agreement with calculations, through the spectral analysis of HPT's with and without resonant cavities.
- A wavelength demultiplexing receiver composed of Resonant Cavity Enhanced Phototransistors has been demonstrated. Crosstalk attenuations of 15 dB for dual and 12 db for three wavelength demultiplexing were achieved. The individual HPTs had an optical gain of 500 at resonant modes. Theoretical calculations predict crosstalk attenuation levels as high as 40 db for high reflection mirrors on both ends of the cavity.
- Ge/GaAs junctions have been investigated and their electrical performance is nearly ideal. This heterojunction system is promising for optical device applications.
- GaAs multiple quantum well reflector modulators grown on Si with 4:1 contrast ratios have been demonstrated. This is by far the best reported value for GaAs reflector modulators grown on Si. Pairs of GaAs asymmetric, coupled quantum wells were used as the absorbing medium and a dielectric stack AlAs/AlGaAs mirror was incorporated in the n region of the p-i-n device. The 4:1 contrast ratio is achieved at 9 Volt bias voltage as opposed to the 2:1 contrast ratio obtained for a similar device using uncoupled MQW's.

C. Plans for next year's research

- Optimization of growth conditions and characterization of high quality InP, InGaP and InGaAsP layers.

GAS SOURCE MBE and UHV-ECR CVD



- Hydrogen plasma cleaning of InP substrates and subsequent cleaning will be attempted for characterizing the surface morphology. In addition, this low temperature cleaning may pave the way for patterned growth of lateral confinement devices.
- InGaAsP/InGaAs/InP material systems will be utilized in an attempt to realize graded index guide, low threshold current density lasers. Development of InGaAs based laser diodes in a vertical array will be attempted at a later date.
- Incorporation of InGaAs/GaAs as well as InGaAsP superlattice as the absorbing medium in reflector modulators for improved modulation ratio will be investigated.
- Ge/GaAs Heterojunction Phototransistors will be studied.
- Optical detectors operating in the 1.3 μ m- 1.55 μ m wavelength range will be grown using the GSMBE. This region of the electromagnetic spectrum is particularly important since it is a low loss region for optical fibers.
- Improved crosstalk on wavelength demultiplexing HPTs.

D. List of Publications/Reports/Presentations

• Papers Published in Refereed Journals

1. M. S. Ünlü, K. Kishino, J. I. Chyi, L. Arsenault, J. Reed, N. Mohammad and H. Morkoç, "Resonant cavity enhanced AlGaAs/GaAs Heterojunction Phototransistor with an intermediate InGaAs layer in the collector", Appl. Phys. Lett. **57**, 750- 752 (1990).
2. M. S. Ünlü, K. Kishino, J. I. Chyi, L. Arsenault, J. Reed and H. Morkoç, "Wavelength demultiplexing Heterojunction Phototransistor", Electron. Device Lett. (to be published).
3. S. N. Mohammad, M. S. Ünlü and H. Morkoç, "Optically controlled current voltage characteristics of ion implanted MESFETs", Solid State Electronics (accepted for publication).
4. A. Salvador, K. Adomi, K. Kishino, M. S. Ünlü and H. Morkoç, "GaAs multiple quantum well reflector modulator with 4:1 contrast ratio on Si ", J. Appl. Phys. (accepted for publication).
5. A. Salvador, J. Reed, N. S. Kumar, M. S. Ünlü and H. Morkoç, "Electroabsorption in GaAs Asymmetric Coupled Quantum Wells ", Surface Science, Vol. **288**, 188 (1990).
6. K. Kishino, M.S. Ünlü, J.I. Chyi, L. Arsenault, J. Reed, and H. Morkoç, "Resonant Cavity Enhanced (RCE) Photodetectors", to be submitted to IEEE Journal of Quantum Electronics.

- Non-refereed Publications and Published Technical Reports

1. M. S. Ünlü, J. I. Chyi, K. Kishino, J. Reed, S. N. Mohammad and H. Morkoç, "Gain and spectral response of molecular beam epitaxially grown AlGaAs/GaAs heterojunction phototransistor with an intermediate InGaAs layer in the collector", Conference on Lasers and Electro-optics 1990 Technical Digest Vol.7, 466 (1990).
2. A. Salvador, K. Adomi, K. Kishino, M. S. Ünlü and H. Morkoç, "GaAs multiple quantum well reflector modulators grown on Si", Conference Digest, LEOS Summer Topical on Integrated Optoelectronics, p. 62 (1990).

- Presentations

- a. Invited

1. H. Morkoç, "Materials and Material Processing Challenges for OEICs", LEOS Summer Topical on Integrated Optoelectronics, July 30-Aug. 1 1990.

- b. Contributed

1. M. S. Ünlü, J. I. Chyi, K. Kishino, J. Reed, S. N. Mohammad and H. Morkoç, "Gain and spectral response of molecular beam epitaxially grown AlGaAs/GaAs heterojunction phototransistor with an intermediate InGaAs layer in the collector", Conference on Lasers and Electro-optics, May 21-25 1990.
2. A. Salvador, K. Adomi, K. Kishino, M. S. Ünlü and H. Morkoç, "GaAs multiple quantum well reflector modulators grown on Si", LEOS Summer Topical on Integrated Optoelectronics, July 30- Aug. 1 1990.

- Books (and sections thereof)

1. K. Adomi, J-I. Chyi, S.F. Fang, T.C. Shen, S. Strite, and H. Morkoç, "MBE Growth of GaAs and other Compound Semiconductors with Applications to Devices ", a book chapter to appear in "Processes in the Fabrication of GaAs Devices and Circuits", ed. B.L. Sharma, Trans Tech Publications.
2. S.F. Fang and H. Morkoç, "Lattice Mismatched Epitaxy", a chapter in the book "Integrated Optoelectronics", ed. R. Kaplan, Academic Press Boston.

E. List of Honors/Awards

1. An AFOSR graduate fellowship was awarded to S. Strite

F. Participants and Their Status

D. Biswas	graduate student
J. I. Chyi	graduate student (Ph.D Aug 1990)
S. F. Fang	post doc
H. Morkoç	Principal Investigator
J. Reed	graduate student
A. A. Salvador	graduate student
S. Strite	graduate student
M. S. Ünlü	graduate student

G. Other sponsored research during FY90

Title	Sponsor	Duration
N00014-86-K-0513	ONR	4/01/86-12/31/90
N00014-89-J-1780	ONR	5/21/89-10/31/90
NSF ECS 88-22406	NSF	3/01/89-2/28/91
AFSOR 89-0239	AFSOR	1/01/90-12/31/90

SUMMARY OF FY90
PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS/PARTICIPANTS
(Number Only)

	This Project	ONR Other ONR	non ONR
a. Number of Papers Submitted to Referred Journal but not yet published:	4	1	_____
b. Number of Papers Published in Refereed Journals:	2	11	_____
c. Number of Books or Chapters Submitted but not yet Published:	2	2	_____
d. Number of Books or Chapters Published:	0	0	_____
e. Number of Printed Technical Reports & Non-Referred Papers:	2	0	_____
f. Number of Patents Filed:	0	0	_____
g. Number of Patents Granted:	0	0	_____
h. Number of Invited Presentations at Workshops or Prof. Society Meetings:	1	2	_____
i. Number of Contributed Presentations at Workshops or Prof. Society Meetings:	2	2	_____
j. Honors/Awards/Prizes for Contract/Grant Employees: (selected list attached)	1	3	_____
k. Number of Graduate Students and Post-Docs Supported at least 25% this year on contract grant:	6	7	_____
Grad Students: TOTAL	6	7	_____
Female	0	1	_____
Minority	0	0	_____
Post Doc: TOTAL	1	0	_____
Female	0	0	_____
Minority	0	0	_____
l. Number of Female or Minority PIs or CO-PIs			
New Female	0	0	_____
Continuing Female	0	0	_____
New Minority	0	0	_____
Continuing Minority	0	0	_____

Enclosure (4)